

CLAIMS

Having thus described our invention in detail, what we claim as new and desire to secure by the Letters Patent is:

- 1 1. A porous, low-k dielectric film comprising:
 - 2
 - 3 a first phase of monodispersed pores having a diameter of from about 1 to about 10 nm that are substantially uniformly spaced apart and are essentially located on sites of a three-dimensional periodic lattice; and
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 - 5
 - 6 a second phase surrounding said first phase, wherein said second phase is a solid phase which includes (i) an ordered element that is composed of nanoparticles having a diameter of from about 1 to about 10 nm that are substantially uniformly spaced apart and are essentially arranged on sites of a three-dimensional periodic lattice, and (ii) a disordered element comprised of a dielectric material having a dielectric constant of less than about 2.8.
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- 1 2. The porous, low-k dielectric film of Claim 1 wherein said nanoparticles are comprised of Si, C, O and H.
- 1 3. The porous, low-k dielectric film of Claim 1 wherein said film has an effective dielectric constant of less than about 2.0.
- 1 4. The porous, low-k dielectric film of Claim 1 wherein said film has an effective dielectric constant of about 1.8 or less.
- 1 5. The porous, low-k dielectric film of Claim 1 wherein said monodispersed pores have a diameter of from about 1 to about 5 nm.

1 6. The porous, low-k dielectric film of Claim 5 wherein said monodispersed pores
2 have a diameter of about 3 nm.

1 7. The porous, low-k dielectric film of Claim 1 wherein said pores are separated by a
2 center-center distance V_{cc} .

1 8. The porous, low-k dielectric film of Claim 7 wherein V_{cc} between each pore is
2 from about 2 to about 10 nm.

1 9. The porous, low-k dielectric film of Claim 8 wherein V_{cc} between each pore is
2 from about 3 to about 6 nm.

1 10. The porous, low-k dielectric film of Claim 1 wherein said pores are separated by
2 an edge-edge distance V_{ee} .

1 11. The porous, low-k dielectric film of Claim 10 wherein V_{ee} between each pore is
2 from about 1 to about 8 nm.

1 12. The porous, low-k dielectric film of Claim 11 wherein V_{ee} between each pore is
2 from about 2 to about 5 nm.

1 13. The porous, low-k dielectric film of Claim 1 wherein said pores and said
2 nanoparticles are separated by a distance AB.

1 14. The porous, low-k dielectric film of Claim 13 wherein AB is from about 1 to
2 about 10 nm.

1 15. The porous, low-k dielectric film of Claim 14 wherein AB is from about 2 to
2 about 50 nm.

1 16. The porous, low-k dielectric film of Claim 1 wherein said nanoparticles have a
2 diameter of from about 2 to about 3.0 nm.

1 17. The porous, low-k dielectric film of Claim 1 wherein said low-k dielectric binder
2 has a dielectric constant of about 2.8 or less.

1 18. The porous, low-k dielectric film of Claim 1 wherein said low-k dielectric binder
2 is selected from the group consisting of polyarylene ethers, thermosetting polyarylene
3 ethers, aromatic thermosetting resins, Si-containing polymers, amorphous alloys
4 comprised of Si, C, O and H that may, or may not, be doped with oxide,
5 methylsilsesquioxane (MSQ), hydrogensilsesquioxane (HSQ), phenylsilsesquioxane
6 (PSQ), and mixtures or complexes thereof.

1 19. The porous, low-k dielectric film of Claim 18 wherein said low-k dielectric binder
2 is MSQ, HSQ, PSQ or a mixture of MSQ and HSQ.

1 20. The porous, low-k dielectric film of Claim 1 wherein said film has a hardness of
2 about 0.2 GPa or greater.

1 21. The porous, low-k dielectric film of Claim 20 wherein said film has a hardness of
2 from about 0.2 to about 0.4 GPa.

1 22. The porous, low-k dielectric film of Claim 1 wherein said film has a Modulus of
2 about 2.0 GPa or greater.

1 23. The porous, low-k dielectric film of Claim 22 wherein said film has a Modulus of
2 from about 2 to about 4 GPa.

1 24. An interconnect structures which includes at least a porous, low-k dielectric film
2 formed between metal wiring features, wherein said porous, low-k dielectric film

3 comprises a first phase of monodispersed pores having a diameter of from about 1 to
4 about 10 nm that are substantially uniformly spaced apart and are essentially located
5 on sites of a three-dimensional periodic lattice; and a second phase surrounding said
6 first phase, wherein said second phase is a solid phase which includes (i) an ordered
7 element that is composed of nanoparticles having a diameter of from about 1 to about
8 10 nm that are substantially uniformly spaced apart and are essentially arranged on
9 sites of a three-dimensional periodic lattice, and (ii) a disordered element comprised of
10 a dielectric material having a dielectric constant of about 2.8 or less.

1 25. The interconnect structure of Claim 24 wherein said nanoparticles are comprised
2 of Si, C, O and H.

1 26. The interconnect structure of Claim 24 wherein said film has an effective
2 dielectric constant of less than about 2.0.

1 27. The interconnect structure of Claim 26 wherein said film has an effective
2 dielectric constant of about 1.8 or less.

1 28. The interconnect structure of Claim 24 wherein said monodispersed pores have a
2 particle diameter of from about 1 to about 5 nm.

1 29. The interconnect structure of Claim 24 wherein said monodispersed pores have a
2 particle diameter of about 3 nm.

1 30. The interconnect structure of Claim 24 wherein said pores are separated by a
2 center-center distance V_{cc} .

1 31. The interconnect structure of Claim 30 wherein V_{cc} between each pore is from
2 about 2 to about 10 nm.

1 32. The interconnect structure of Claim 31 wherein V_{cc} between each pore is from
2 about 3 to about 6 nm.

1 33. The interconnect structure of Claim 24 wherein said pores are separated by an
2 edge-edge distance V_{ee} .

1 34. The interconnect structure of Claim 33 wherein V_{ee} between each pore is from
2 about 1 to about 8 nm.

1 35. The interconnect structure of Claim 34 wherein V_{ee} between each pore is from
2 about 2 to about 5 nm.

1 36. The interconnect structure of Claim 24 wherein said pores and said nanoparticles
2 are separated by a distance AB.

1 37. The interconnect structure of Claim 36 wherein AB is from about 1 to about 10
2 nm.

1 38. The interconnect structure of Claim 37 wherein AB is from about 2 to about 5 nm.

1 39. The interconnect structure of Claim 24 wherein said nanoparticles have a diameter
2 of from about 2 to about 3.0 nm.

1 40. The interconnect structure of Claim 24 wherein said low-k dielectric binder has a
2 dielectric constant of about 2.8 or less.

1 41. The interconnect structure of Claim 24 wherein said low-k dielectric binder is
2 selected from the group consisting of polyarylene ethers, thermosetting polyarylene
3 ethers, aromatic thermosetting resins, Si-containing polymers, amorphous alloys
4 comprised of Si, C, O and H that may, or may not, be doped with oxide,

5 methylsilsesquioxane (MSQ), hydrogensilsesquioxane (HSQ), phenylsilsesquioxane
6 (PSQ), and mixtures or complexes thereof.

1 42. The interconnect structure of Claim 41 wherein said low-k dielectric binder is
2 MSQ, HSQ, PSQ or a mixture of MSQ and HSQ.

1 43. The interconnect structure of Claim 24 wherein said metal wiring features are
2 metal lines or vias.

1 44. The interconnect structure of Claim 24 wherein said metal wiring features are
2 composed of a conductive metal selected from the group consisting of Cu, Al, W, Pt
3 and alloys or combinations thereof.

1 45. The interconnect structure of Claim 24 further comprising a substrate.

1 46. The interconnect structure of Claim 45 wherein said substrate is a semiconductor
2 wafer, a dielectric layer, a barrier layer or a combination thereof.

1 47. The interconnect structure of Claim 24 wherein said structure is a dual damascene
2 structure.

1 48. The interconnect structure of Claim 24 wherein said structure is a gapfill
2 structure.

1 49. A method of fabricating a porous, low-k dielectric film comprising the steps of:
2
3 (a) coating a suspension of water soluble or water vapor soluble oxide particles with a
4 surface ligand group which is effective in preventing agglomeration of said water
5 soluble or water vapor soluble oxide particles, yet maintains solubility of the oxide

6 particles in said suspension, while separating forming monodispersed SiCOH particles
7 having a particle diameter of from about 1 to about 10 nm;

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9 (b) adding said coated water soluble or water vapor soluble oxide particles and said
10 monodispersed particles to a solution containing a dielectric binder material having a
11 dielectric constant of about 2.8 or less so as to form a precursor mixture;

12

13 (c) coating said precursor mixture on to a surface of a substrate;

14 (d) subjecting said coated precursor mixture to a curing process, said curing process
15 including at least a step which is capable of ordering of said particles in a three-
16 dimensional lattice and a step of forming a crosslinked film;

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18 (e) removing said coated water soluble or water vapor soluble oxide particles from
19 said crosslinked film so as to form pores in said film; and

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21 (f) annealing said film containing said pores so as to remove residual water and
22 hydroxyl groups from said film, wherein said film comprises a first phase of
23 monodispersed pores having a diameter of from about 1 to about 10 nm that are
24 substantially uniformly spaced apart and are essentially located on sites of a three-
25 dimensional periodic lattice; and a second phase surrounding said first phase, wherein
26 said second phase is a solid phase which includes (i) an ordered element that is
27 composed of nanoparticles having a diameter of from about 1 to about 10 nm that are
28 substantially uniformly spaced apart and are essentially arranged on sites of a three-
29 dimensional periodic lattice, and (ii) a disordered element comprised of said binder.

1 50. The method of Claim 49 wherein said monodispersed particles are comprised of
2 Si, C and H and said nanoparticles are comprised of Si, C, O and H.

1 51. The method of Claim 49 wherein said oxide particles are silicon oxide,
2 germanium oxide, or mixtures thereof.

1 52. The method of Claim 49 wherein said suspension includes a solvent selected from
2 the group consisting of an alcohol, an alkane, a ketone, an ether, an aromatic, and a
3 carboxylic acid.

1 53. The method of Claim 49 wherein said surface ligand group is selected from the
2 group consisting of an organosilane, an organohalosilane, germanium analogs of said
3 organosilane or organohalosilane, long chain carboxylic acids containing from 4 to 18
4 carbon atoms, long chain alcohols containing from 4 to 18 carbon atoms, long chain
5 alkylamines containing from 4 to 18 carbon atoms, long chain phosphonic acids
6 containing from 4 to 18 carbon atoms, and long chain sulfonic acids containing from 4
7 to 18 carbon atoms.

1 54. The method of Claim 49 wherein said dielectric binder is selected from the group
2 consisting of polyarylene ethers, thermosetting polyarylene ethers, aromatic
3 thermosetting resins, Si-containing polymers, amorphous alloys comprised of Si, C, O
4 and H that may, or may not, be doped with oxide, methylsilsesquioxane (MSQ),
5 hydrogensilsesquioxane (HSQ), phenylsilsesquioxane (PSQ), and mixtures or
6 complexes thereof.

1 55. The method of Claim 54 wherein said dielectric binder is MSQ, HSQ, PSQ or a
2 mixture of MSQ and HSQ.

1 56. The method of Claim 49 wherein said coating step is a spin-coating process.

1 57. The method of Claim 49 wherein said curing process includes an optional hot
2 bake process.

1 58. The method of Claim 57 wherein said optional hot bake process is carried out on a
2 hot plate in air at a temperature of from about 80° to about 200°C for a time period of
3 from about 1 to about 10 minutes.

1 59. The method of Claim 49 wherein said ordering curing step is carried out in a
2 furnace using an inert ambient that includes less than about 50 ppm O₂ or H₂O.

1 60. The method of Claim 59 wherein said ordering curing step is carried out at a
2 temperature of from about 200° to about 300°C for a time period of from about 30 to
3 about 120 minutes.

1 61. The method of Claim 49 wherein said crosslinking curing step is carried out at a
2 temperature of from about 350° to about 450°C for a time period of from about 60 to
3 about 240 minutes.

1 62. The method of Claim 49 wherein step (e) includes immersing said crosslinked
2 film in water or exposing said crosslinked film to water vapor.

1 63. The method of Claim 49 wherein said annealing step out in a furnace using an
2 ambient that includes less than about 50 ppm O₂ or H₂O.

1 64. The method of Claim 63 wherein said annealing step is carried out at a
2 temperature of from about 200° to about 400°C for a time period of from about 60 to
3 about 240 minutes.

1 65. The method of Claim 49 wherein step (a) includes injecting 1 to 5 weight % of a
2 solution containing a silicon precursor into a hot solution containing said surface
3 ligand and an organic solvent containing between 0.1 to 1 % water.

1 66. The method of Claim 65 wherein said silicon precursor is a siloxane or a
2 silsesquioxane.